

34-Meter Antenna-Subreflector Translations to Maximize RF Gain

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The extension of the 26-meter antenna to 34-meter diameter decreased the F/D ratio. This F/D change resulted in unacceptable gain losses due to the hyperboloid's lateral deflections. A three-direction translating mounting device was added to the hyperboloid. This device was controlled by a microprocessor to minimize the offsets of the phase centers in the cassegrain RF system and also compensated for boresight directions. This article discusses the use of the Radiation Program to predict the gain losses from displacements computed by a structural computing program using an analytical model of the 34-meter reflector structure. Field test results showed accurate predictions for the Y and Z hyperboloid translations. In the X-direction, the prediction value was low. However, the computed gain losses vs primary foci offsets by the radiation program were verified by field tests.

I. Introduction

The surface panels of the primary reflector and subreflector are rigged or set to the design positions with the 34-meter HA-DEC antenna pointing at 0 (zero) hour angle and -15 degrees declination angle. This rigging position minimizes the structural distortions as described in Ref. 1. When the antenna is moved from the rigged position, gravity loading deflections result in distorted radio frequency (RF) paths as shown in Fig. 1. Offsets of the phase centers occur. These offsets result in varying degrees of RF gain losses to the antenna system. The offsets at the RF feed result in negligible losses; however, the offsets between the focus of the best fit paraboloid and the virtual secondary phase center could result in unacceptable gain losses.

The value of the gain loss in dB per offset unit is a function of the focal-length-to-aperture diameter (F/D) of the primary

reflector and the operating RF frequency. For our case, the decrease in the F/D ratio resulting from increasing the aperture diameter from 26 to 34 meters tripled the gain loss in dB per expected offset of 5.08 cm (2 in.).

Focusing in the axial direction to minimize gain loss results in negligible boresight shift. However, lateral focusing will change the boresight direction. A control system interconnecting the lateral motion of the subreflector to the pointing system becomes a necessity.

II. Solution Descriptions

A full or complete structural analytical model of the 34-meter HA-DEC reflector structure, which rotates about the elevation axis, was iteratively designed using the IDEAS Program (Ref. 2). Three 1.0 gravity loadings were applied and a

paraboloid was best-fitted to the distorted surface panel attaching points on the reflector structure. The three loading directions were:

- (1) Parallel to the elevation axis (X-direction) or also in the hour angle motion direction.
- (2) Normal to the elevation axis (Y-direction).
- (3) Parallel to the symmetric axis (Z-direction) or the RF boresight direction.

The deflections of the RF feed and the hyperboloid system were also obtained from the IDEAS answers (see Fig. 1 and Table 1). The gain losses from phase center offsets at the paraboloid's focus were evaluated by a version of the JPL-developed Radiation Program, as noted in Ref. 3, which was coded to accept three-component distortion vectors as computed by a structural computing problem (IDEAS).

As in the paraboloid best-fitting rms program (Ref. 4), the surface at a selected point on the paraboloid's surface is assumed to have moved parallel to the original surface. It follows that any distortion vector, OA of Fig. 2, can be normalized as OC. By geometric relationships, OB equals OD and the full pathlength error ODE equals $OD(1 + \cos \psi)$ or $2 \times OC \times \cos(\psi/2)$.

The above-described algorithm permits the simulation of a phase center offset at the focus in the Radiation Program by moving the paraboloid as a unit with equal distortion vectors at each node under a stationary focus point. For maintaining computing accuracy during the integration in the Radiation Program, 341 nodes, approximately equally spaced over the paraboloid's surface, were used. The RF amplitude illumination input to the program was the same as measured for the 64-meter antenna (Fig. 3).

By inputs of varied axial and lateral offsets to the Radiation Program with different focal lengths, the curves shown in Fig. 4 were generated. The gain losses in dB's were converted to the equivalent rms distortion figure by the Ruze equation:

$$\text{Gain Loss} = e^{-16\pi^2 \frac{\text{rms}^2}{\lambda}}$$

where

rms = root-mean-square half-pathlength errors and

λ = RF wavelength.

The gain loss conversion from dB to Ruze's rms equivalent loss resulted in RF frequency-independent curves. It should be

noted that the linear relationship between the offset and the gain loss in rms for any antenna resulted from the Radiation Program computations using a maximum of only three wavelengths offset. Figure 5 defines the computed or predicted gain loss in dB vs foci offset for the 34-meter HA-DEC antennas at the DSS stations.

III. Field Results

The hyperboloid of the 34-meter HA-DEC was mounted to the apex of the quadripod with adjustable means to allow translational motions of plus or minus 7.62 cm (3 in.) in the X, Y, and Z directions. The control was by a microprocessor, which also compensated the pointing of the boresight change created by the lateral shifts.

A look-up table in the microprocessor was initially loaded with computed hyperboloid offset data. The data were computed by a modified program (Ref. 1) using the 1.0 gravity nominal offsets of Table 1. The nominal offsets were from the structural analysis results made initially in the project where the deflection characteristics of the controllable hyperboloid mounts were not known.

Field tests showed that both the Y and Z offsets were correctly predicted using the nominal offsets. However, the X offsets were much larger than predicted. The complete answer to this discrepancy is not known at present. However, by inspection, the X-direction stiffness of the hyperboloid mounting assembly is obviously less than in the Y-direction. The X offset of -4.83 cm of Table 1 was increased to -7.45 cm to maintain minimum gain loss. During the field tests, the gain losses vs offsets were measured. The field test results confirmed the correctness of the predicted curves of Fig. 5.

If an extreme eastward listening position of 0 deg declination and 75 deg hour angle is assumed (about 12.2 deg to ground) and the required lateral offset is 7.45 cm for 1.0 gravity in the X-direction, then the hyperboloid offset equals:

$$\begin{aligned} \text{Hyperboloid Offset} &= 7.45 \times \cos(35.2 \text{ (polar angle)}) \\ &\quad \times \sin 75 \text{ deg} \\ &= 5.9 \text{ cm} \end{aligned}$$

Since the foci offset itself is a little less than this number, as shown in Fig. 1, then by Fig. 5, about 1 dB gain was saved

using the hyperboloid automatic controls. It should be noted that the gravity and atmospheric losses are largest at these low angles to ground, which also reduces the overall gain.

The gain loss and the reflection factor can also be calculated from curves in Ref. 5, where Ruze has reduced the large amount of computed data by plotting the RF pattern characteristics against a quantity which is a function of the number of half-power beamwidths scanned and the F/D ratio. Although

the curves were necessarily small, it was possible to establish that our computed gain loss checked closely with Ruze's values.

The Radiation Program can use an input RF amplitude pattern as was done in this report, and can also include the feed phase errors if available. The program also accounts for the space loss within the antenna system. Analysis of offset primary reflectors can be made, and the computing costs are nominal for precise answers.

Acknowledgments

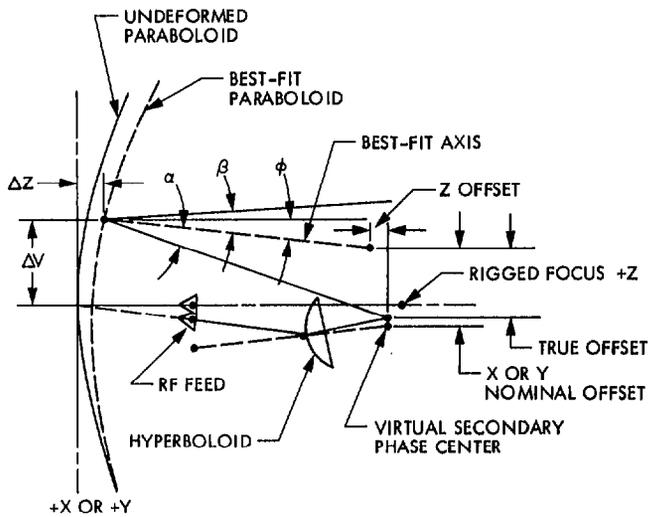
The author wishes to acknowledge the work of Kenneth Ng in developing the 34-meter HA-DEC analytical model and its IDEAS program analysis to output the hyperboloid's displacements. The microwave data furnished by Phil Potter and Dan Bathker and the field tests data verifying Fig. 5 values furnished by Dr. M. J. Klein are also gratefully acknowledged.

References

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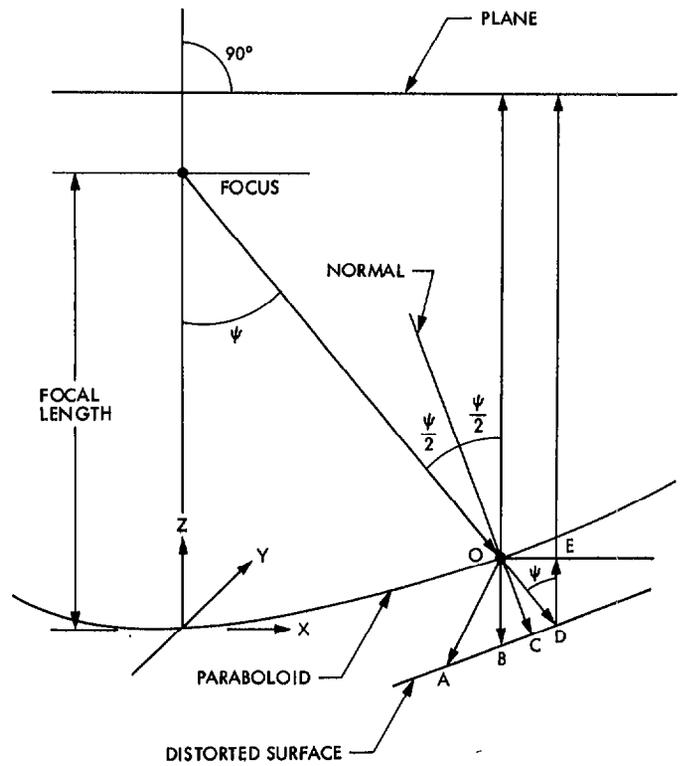
Table 1. 34-meter antenna computed paraboloid and hyperboloid offsets

1.0 gravity loading	Rotation ϕ ,rad	Δv vertex offset, cm	Δz vertex offset, cm	Nominal offset, cm	Best-fit focal length, cm
X	0.004328	-9.40	0.0	-4.83	1097.280
Y	-0.004896	-7.89	0.0	-4.06	1097.280
Z	0.0	0.0	0.27	-0.51	1096.78



F - RIGGED FOCAL LENGTH = 10.9728 m (36 ft)
 D - APERTURE DIAMETER = 34.0 m (111.6 ft)
 F/D = 0.323
 $\frac{\beta}{\alpha}$ - REFLECTION RATIO = 0.77

Fig. 1. 34-meter RF center ray tracing and hyperboloid offset for gravity distorted reflective surfaces



OA = DISTORTION VECTOR (CAN BE OUT OF PLANE OF VIEW)
 OB = DELTA Z ERROR VECTOR
 OC = NORMAL ERROR VECTOR
 ODE = FULL PATHLENGTH ERROR

Fig. 2. RF pathlength error

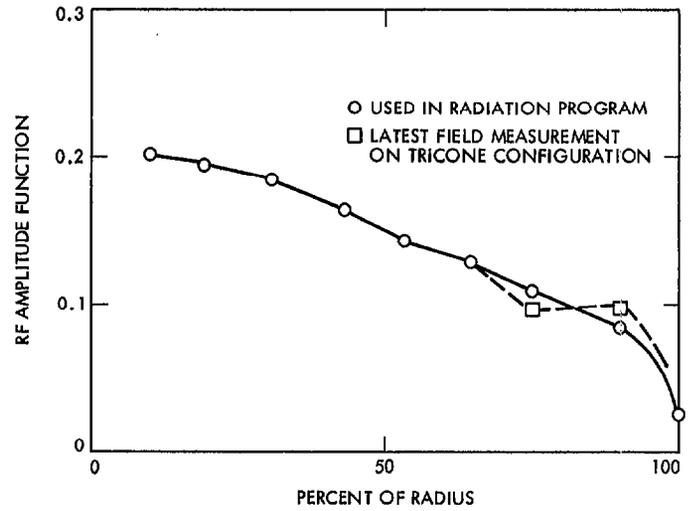


Fig. 3. RF feed amplitude pattern on 64-meter reflector surface

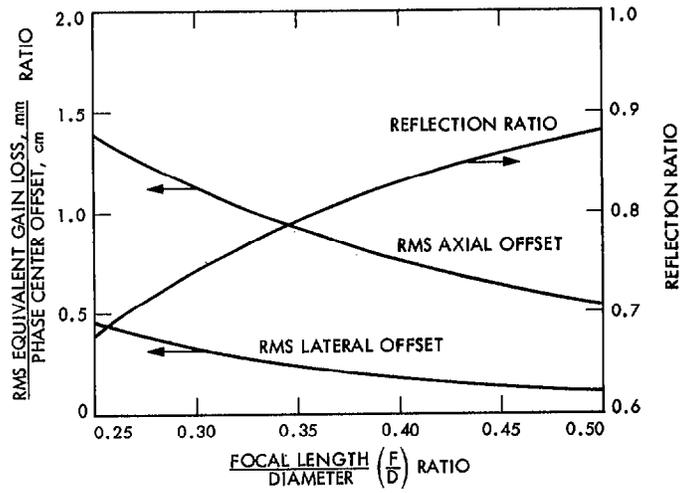


Fig. 4. Gain loss (rms equivalent, mm per cm offset) vs F/D ratio

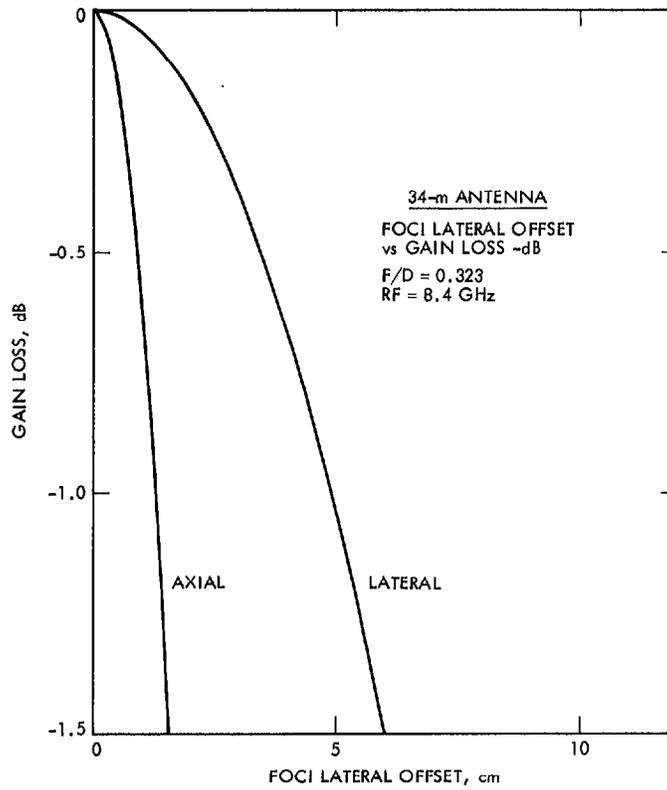


Fig. 5. Foci lateral offset vs gain loss - dB

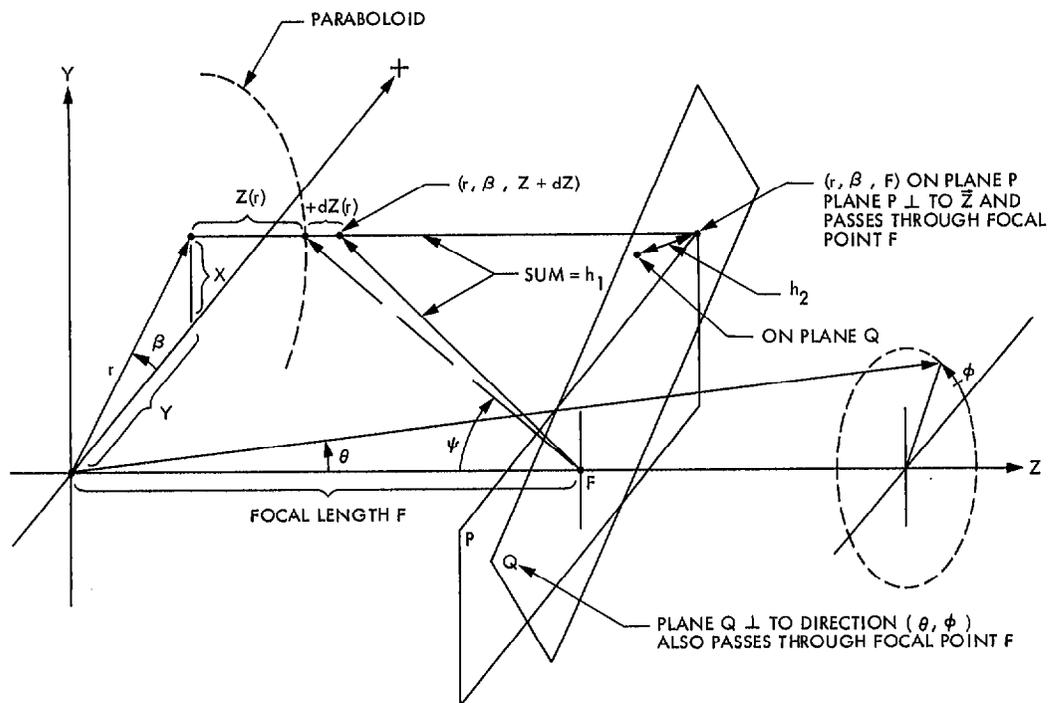


Fig. 6. RF path definitions and direction for the radiation program

Appendix

An abridged initial reporting of the solution algorithms follows for completeness of this discussion. The solution algorithms were developed by P. Potter of the Microwave Subsystem Group and C. Lawson of the Numerical Analysis Group.

The Radiation Program numerically evaluates the following scalar far-field radiation pattern integral (Ref. 6) by the trapezoidal rule approximation:

$$G(\theta, \phi) = \int_0^{r \max} r w(r) dr \int_0^{360^\circ} e^{jh}(\theta, \phi, r, \beta, k) d\beta$$

where

$$G(\theta, \phi) = \text{RF gain in direction } (\theta, \phi) \quad (\text{Fig. 6})$$

$$h(\theta, \phi, r, \beta, k) = h_1(r, \beta, k) + h_2(\theta, \phi, \beta, r, k) + h_3(r, \beta)$$

$$h_1(r, \beta, k) = k(1 + \cos \psi) dz \quad (\text{Fig. 2})$$

$$= k \left| 1 + \frac{F - z(r)}{[F - z(r)^2 + r^2]^{1/2}} \right| dz(r, \beta)$$

$$z(r) = \frac{r^2}{4F}$$

$$h_2(\theta, \phi, r, \beta, k) = kr \sin \theta \cos(\phi - \beta)$$

$$h_3(r, \beta) = \text{feed phase errors}$$

$$k = \text{propagation factor } (2\pi/\lambda)$$

$$\lambda = \text{RF wavelength}$$

$$dz = \text{reflector surface error measured in Z-direction}$$

As shown in Fig. 6, h_1 denotes the pathlength from the focus of the paraboloid to the reflector at the node $(r, \beta, z + dz)$, then to a reference plane P (which passes through the focal point perpendicular to the z -axis) at the point (r, β, F) ; h_2 denotes the pathlength from the plane P to the plane Q

the direction (θ, ϕ) . Plane Q passes through the focal point perpendicular to the direction (θ, ϕ) . The sum $(h_1 + h_2)$ expresses the pathlength in radians minus the constant pathlength property of a paraboloid $2kF$.

As shown previously, the pathlength error in h_1 resulting from the dz error is approximated closely by $(1 + \cos \psi) dz$ (Fig. 2).

The paraboloid reflector surface is defined by

$$r^2 = x^2 + y^2 = 4Fz$$

The normal vector OC at the node (x, y, z) (Fig. 3) has components

$$n_1 = \frac{-2x}{c_1}$$

$$n_2 = \frac{-2y}{c_1}$$

$$n_3 = \frac{4F}{c_1}$$

where

$$c_1 = \sqrt{4x^2 + 4y^2 + 16F^2}$$

The projection of the distortion vector (u, v, w) on the normal has components

$$P_1 = c_2 n_1$$

$$P_2 = c_2 n_2$$

$$P_3 = c_2 n_3$$

where

$$c_2 = un_1 + vn_2 + wn_3$$

The length of the P vector is

$$\|P\| = \sqrt{\sum_{i=1}^3 P_i^2} = c_2$$

The magnitude of dz is

$$|dz| = \frac{\|P\|}{\cos(1/2 \psi)} = \frac{c_2}{n_3} = \frac{un_1 + vn_2 + wn_3}{n_3}$$

Angle ψ is defined as

$$\psi = \arccos \left| \frac{F - z(r)}{(F - z(r))^2 + r^2} \right|$$

The primary output of gain loss is the ratio of the magnitude $G(\theta, \phi)$ to the normalizing factor or perfectly phased antenna value of:

$$G_0 = 36 \int_0^{r \max} r w(r) dr$$